

Statement of Work

Ground Operations Demonstration Unit for Liquid Hydrogen (GODU LH2)

20K Refrigeration System

January 17, 2012

1 INTRODUCTION

1.1 Purpose

NASA Kennedy Space Center (KSC) is developing a Ground Operations Demonstration Unit for Liquid Hydrogen (GODU LH2) to test advance operational concepts, primarily integrated refrigeration and storage (IRAS), for the future launch vehicle servicing applications. The system features a 125 m³ (33,000 gallon) liquid hydrogen tank with an integrated cryogenic refrigerator that can remove energy from the tank and control the state of the propellant inside the tank. The objectives of the overall NASA project are to demonstrate hydrogen zero boil off and zero loss chill down operations, in situ liquefaction, and propellant densification. An external contractor will be utilized to design, fabricate, test and deliver the refrigeration system.

1.2 Scope

This statement of work (SOW) details the requirements for the development of the refrigeration system. The contractor shall provide all labor and materials necessary to perform the design, fabrication, and testing necessary to produce and deliver the refrigeration system to KSC. This statement of work includes necessary refrigeration capacity, fabrication specifications, interface definitions, and delivery requirements.

2 APPLICABLE DOCUMENTS

The following documents are applicable to this SOW:

Specification Number	Description
ASME B31.3	Process Piping
ASME Y14.100	Engineering Drawing Practice
ASME Y14.5	Dimensions and Tolerancing
NFPA 70	National Electric Code

3 REQUIREMENTS

The GODU LH2 project seeks to procure a cryogenic refrigeration system capable of delivering refrigeration power to the inside of a 125 m³ LH2 tank. If the refrigeration system is a regenerative system with cooling at a cold head, the refrigeration is to be delivered to the inside of the IRAS tank using a cold gaseous helium transport loop. Recuperative cycles may not need separate circulator. A functional diagram of the required system is shown below.

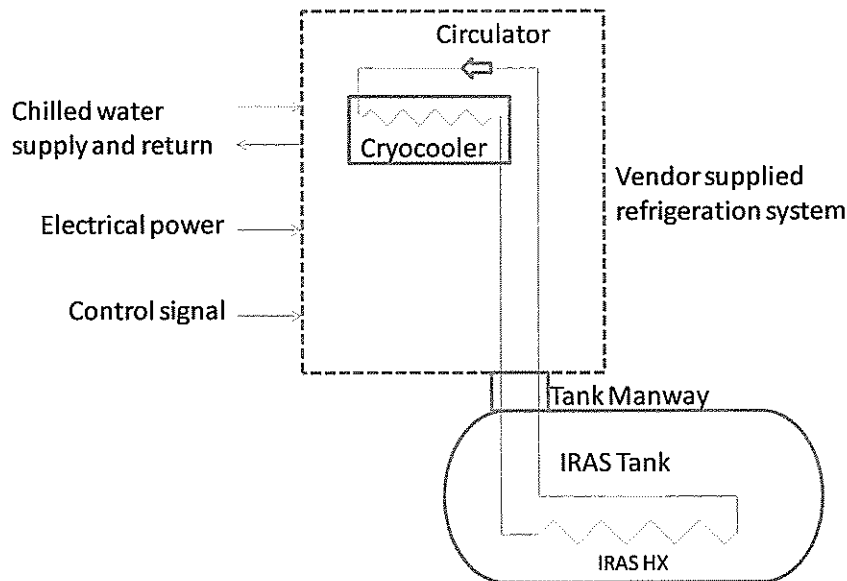


Figure 1) GODU LH2 functional diagram with refrigeration system interfaces

3.1 Performance requirements

- 1) The refrigeration system shall provide 500 W (+500 W/-0 W) of net refrigeration at 20.3 K (+/- 0.1 K) for nominal operations (measured at the IRAS tank interface)
- 2) The refrigeration system shall provide a maximum no load temperature of 15 K (measured at the IRAS tank interface)
- 3) The refrigeration system shall use commercial cryocooler with demonstrated specific power of less than 160 W/W.
- 4) The refrigeration system shall deliver the refrigeration to a tank interface using cold helium transport loop. The specification for the helium transport loop is a maximum helium pressure of 40 bar (580 psi), and a maximum delta temperature across the IRAS heat exchanger of 1.25 K.
- 5) The refrigeration system will be used in two modes of operation. Zero boil off (ZBO) mode will require control of the refrigeration system output to control the LH2 tank pressure. The ZBO mode is estimated to require approximately 300W of cooling to remove only the heat leak into the tank.
- 6) The second mode of operation is propellant densification, where the refrigerator operates at maximum capacity, to cool the LH2 to the lowest possible temperature. The refrigeration system shall be able to operate at maximum capacity for up to 5000 hours continuously.
- 7) The refrigeration system shall provide instrumentation necessary to verify the health and performance of the refrigeration system including cold head temperatures and cryocooler/circulator motor speed. The helium transport loop shall include inlet and outlet temperature measurements as close as possible to the IRAS tank interface.
- 8) Liquid nitrogen precooling may be used to increase the cooling capacity during densification operations, however the refrigeration system shall be

capable of delivering at least 350W of cooling at 20.3 K without LN2 precooling.

3.2 Interface requirements

- 1) A helium transport loop shall be capable of delivering the cooling between the refrigerator and the top of the IRAS tank, approximately 13 meters. This distance includes 4 meters of horizontal run near ground level, 5 meters of vertical run to the top of the tank, and 4 meters of horizontal run at tank height to the manway top. A picture of the IRAS tank is shown in Figure 2.
- 2) Refrigerator to IRAS tank interface – The IRAS tank interface is a 60 cm diameter flange on the tank manway. The manway uses a plug design with internal vacuum shell as currently shown in Figure 3. The government will provide the modified IRAS tank manway plug with mating connectors and IRAS heat exchanger. The contractor shall provide a low heat leak interface to the manway plug.
- 3) The maximum operating pressure of the helium transport line is 40 bar (580 psi). Pressure vessels used in the helium transport loop (accumulator, etc.), shall be designed and stamped in accordance with ASME Boiler and Pressure Vessel Code Section VIII.
- 4) The helium transport loop shall have the capability of being pressurized and vented manually at the test site. There shall be a pressure transducer capable of providing helium loop pressure to the test site instrumentation system.
- 5) Refrigerator heat rejection to be provided by government supplied water circulation system
- 6) Facility electrical power to be provided by government supplied electrical feed. The facility has a 480 VAC, 3 phase 1000A service, and the government is responsible if transformer is needed.
- 7) Controls – The refrigerator shall have the capability of continuous control of delivered refrigeration to the IRAS tank between 100% and 50% capacity. The government shall provide a low voltage signal to the refrigeration system for this control point.
- 8) The refrigeration system shall be located inside an enclosure with approximate dimensions of 2.4 m wide x 12 m long (government provided). The enclosure is purged so there are no NFPA Class 1 Division 2 requirements on the refrigerator electrical system. The helium transport loop shall run from the inside of the enclosure to the outside top of the tank. Transfer lines outside the enclosure shall be designed for outdoor use and any electrical connections outside the enclosure shall be NFPA 70 Class 1 Div 2



Figure 2) IRAS Tank with upper manway

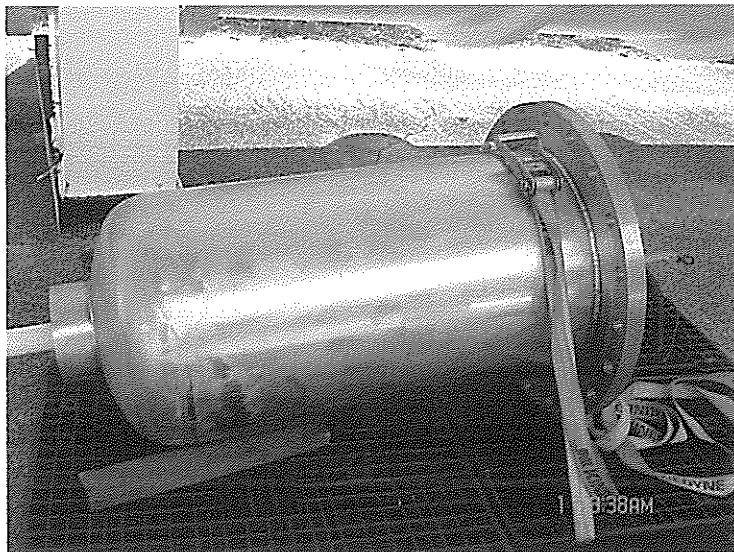


Figure 3) Tank manway plug with 60 cm diameter interface flange

3.3 General requirements

- 1) The Contractor shall provide detailed, signed certified shop drawings that meet the requirements of ASME B 31.3, ASME Y14.100 and ASME Y14.5.
- 2) Transfer piping shall be designed to meet the requirements of ASME B31.3.
- 3) The Contractor shall provide all materials and labor for design, analysis, fabrication, validation, and delivery of the refrigeration system. Final installation at the GODU test site shall be performed by the government
- 4) The Contractor shall perform stress, thermal, and flow performance analyses for the refrigeration system to verify the performance requirements.

- 5) The Contractor shall perform acceptance testing for the refrigeration system as specified in section 5.0 of this SOW
- 6) The Contractor shall conduct Non Destructive Evaluation (NDE), and complete successful acceptance tests, cleaning, certification, shipment preparation, and delivery of the refrigeration system to KSC site
- 7) NASA (or its designated representative agent) reserves the right to witness and inspect any part during the construction, fabrication, assembly and test at the Contractor or Contractor's suppliers / subcontractors site.

4 FABRICATION AND VERIFICATION REQUIREMENTS

All fabrication and verification requirements are the responsibility of the contractor. Verification of the inspection and testing described below shall be provided prior to contractor delivery of the refrigeration system.

- 1) Documentation: The contractor shall provide a complete documentation package as defined in Section 8.0. The contractor shall also provide detailed analysis of the thermal and fluid characteristics of the system to identify system losses and verify the proposed design meets the intent of this SOW.
- 2) Transfer Lines: The contractor shall design, fabricate, inspect, and test the inner process lines in accordance with ASME B31.3 Piping Code or equivalent. The MOP is 40 bar and the service temperature range is 14 K to 300 K.
- 3) Vacuum Jacket (VJ): The contractor shall design, fabricate, inspect, and test the VJ in accordance with ASME B31.3. The VJ shall be designed for an internal vacuum and atmospheric external pressure.
- 4) Piping and Bellows: The contractor shall design, fabricate, inspect, and test the piping and bellows in accordance with ASME B31.3 and the Standards of the Expansion Joint Manufacturers Association. Normal bellows movement shall not exceed 75% of the maximum rated movement for a design cycle life of 5,000 cycles.
- 5) Materials: All wetted materials shall be 304L or 316L stainless steel, unless otherwise approved.
- 6) Welding: All welding shall be performed by welders qualified by ASME Sect IX or equivalent. Welds shall meet the requirements of ASME B31.3 for full penetration welds.
- 7) Coatings: Coat all exterior surfaces of refrigeration system using epoxy primer and epoxy paint
- 8) Nameplate and Marking: The pipe sections and refrigeration components shall be permanently and legibly marked with vendor name, part number, fabrication date, hydrostat date, pressure rating, serial number, and flow direction.
- 9) Radiographic Testing: All welds shall be subject to 5% random radiographic testing or equivalent pre-approved procedure. Do not use liquid penetrant on welds.

- 10) Vacuum Bake Out: Heat line to 350-400K and hold for 48 hours at < 0.2 kPa.
- 11) Pressure Test: Pressure vessels and piping shall be pressure tested in accordance with ASME Code Section VIII Division 1 and ASME B31.3, except that a pneumatic pressure test shall not be at less than 110% of the design pressure.
- 12) Cold Shock: Prior to leak test, the inner line shall be cold shocked with liquid nitrogen for a minimum duration of 1 hour. After completion of cold shock test, the inner line shall be allowed to return to ambient temperature, using an ambient nitrogen purge if necessary. Moisture shall be prevented from forming on the inside of components as the assembly warms.
- 13) Leak Test: After cold shock, the completed assembly shall be leaked tested by pressurizing process lines/component to operating pressure with a minimum 10% helium/90% nitrogen mixture and check with hand probe for leaks around welds and fittings. During the test no leakage shall be detected using a helium mass spectrometer, including the vacuum annulus, previously evacuated. The helium mass spectrometer shall be calibrated to a sensitivity of 1×10^{-9} atm-standard cubic centimeters per second (sccs).
- 14) Final Cleaning: After the successful completion of all testing, the entire assembly shall be cleaned. The assembly shall be visually clean (no particulate or nonparticulate matter shall be visible to the normal unaided eye or corrected-vision eye) using visible light and ultraviolet light.
- 15) Helium servicing: The helium transport loop shall be serviced with gaseous helium with a minimum purity of 99.999%.
- 16) Vacuum retention: Prior to shipping, with the assembly at ambient temperature and at or below 10 microns, the vacuum level shall not significantly change (i.e., approx. ± 1 micron) over a 72 hour period, and shall be stable.

5 ACCEPTANCE TESTING

Before shipment to the KSC test site, the Contractor shall thoroughly test the refrigeration system using a dummy load. The dummy load shall have a flow impedance similar (as far as possible) to that predicted for the IRAS tank plumbing and heat exchanger, and shall be equipped with heaters capable of simulating the expected IRAS tank heat loads. The impedance and heat load estimates will be provided by NASA 6 months in advance of the test. Throughout the testing, all sensor data shall be recorded. The raw data shall then be distilled down into a set of performance maps that quantitatively describe the dependence of cooling capacity on flow rate, outlet temperature, and input power; flow rate vs. outlet temperature; and other relations that might facilitate operation during testing at KSC. NASA (or its designated representative agent) reserves the right to witness and inspect any part during the construction, fabrication, assembly and test at the Contractor or Contractor suppliers / subcontractors site. The contractor shall provide 5 day advanced notice of final acceptance testing.

6 SCHEDULE

A kick off meeting shall occur (teleconference is acceptable) between the contractor and NASA engineers no later than 2 weeks after contract award.

A design review shall occur no later than three months after contract award. This design reviews shall occur at the contractor facility. Design drawings and analysis shall be available for review no later than 10 days prior to the review.

The Contractor shall provide a monthly status report. The first report shall be delivered on the first calendar month following the end of the first full month after contract award. Monthly project status reports shall be delivered within 10 calendar days following the end of each month. This report shall provide data for the assessment technical and schedule progress and summarize the results of the entire contract work.

A final evaluation of test results and required acceptance data package materials shall be performed no later than 11 months after contract award. This evaluation test shall occur at the contractor's facility

The completed refrigeration system shall be delivered and accepted at the Kennedy Space Center no later than 12 months after contract award.

7 QUALITY ASSURANCE

All equipment delivered under this specification shall conform to the highest commercial standards for fit, finish, and workmanship.

Inspection Control Point Outline (Mandatory Inspection Points) (MIPs). Special inspections, called MIPs, will be designated by the Government during the performance of this contract. Prior to the start of work, the contractor shall provide the NASA KSC Procurement QAR a schedule / Inspection Control Point Outline (ICPO) which shows the work sequence(s) to be employed during the performance of this Purchase Order. The contractor's schedule/ICPO must indicate what types of contractor inspections will be performed and where in the contract's sequence of events they will be accomplished. If applicable, the schedule/ICPO must also indicate the specification(s) (including revisions) and/or other documentation that will be used to perform the indicated inspections. The Government will identify which inspections/tests/work steps require Government Quality Assurance witness. These inspections/tests and/or work steps will be designated as MIPs. The contractor shall notify The NASA KSC Procurement QAR at least five (5) working days prior to the occurrence of a scheduled, designated MIP. Designation of MIPs does not relieve the contractor of the obligation to perform all contractually required inspections.

Government Source Inspection (GSI) is required on this Purchase Order/Contract prior to invoice product shipment. The contractor shall also notify the responsible QAR at least

five (5) working days in advance of the date goods or services will be ready for tests, inspections, or other Mandatory Inspection Points (MIPs), as required and indicated in the Purchase Order/Contract. MIPs are designated by the Government. Evidence of GSI must be indicated by the QAR's stamp or signature on the contractor's shipping document.

Quality Assurance inspection shall be included, but not limited to the following tasks:

- a. Integrated electrical and mechanical testing
- b. Functional testing
- c. Leak check of assembled hardware
- d. Chemical cleaning of pneumatic system
- e. Hydrostatic testing of pneumatic tubing

8 SUBMITTED DOCUMENTS

An Acceptance Data Package (ADP) shall be maintained through the duration of the contract and contain all correspondence between the Contractor and NASA, quality control documents, final acceptance inspection records and any other documentation required to administer the successful completion of the contract. The ADP shall be included with each shipment for the units or items shipped. A complete ADP for all units will be provided to the NASA Contract Administrator. At a minimum the package will contain the following documents:

- a. Copy of Correspondence (Most Current Documentation on Top/Filed by Hardware Deliverable)
- b. As Built Drawings (redlines) including all schematics, diagrams and Engineering Orders
- c. Commercial Warranties
- d. Specification sheets on all components, including performance maps of cryocoolers and circulators.
- e. Calibration curves for provided instrumentation
- f. Approved Deviations and Waivers
- g. Requests for Information / Clarification
- h. Approved Acceptance Test Procedures
- i. Final Acceptance Test Records including subcontractors
- j. Material Certifications
- k. Subtier Contractor Identification
- l. Welder/Welder Operator Certifications
- m. Welding Procedures and Weld Procedure Qualifications
- n. Welding Inspectors Certification and Qualifications
- o. Weld Record/Map/Radiography
- p. Quality Inspection Control Outline and Record
- q. Hazards analysis
- r. Critical/spare parts lists and maintenance instructions
- s. Results of thermal, stress, and fluid analysis
- t. Punch list with disposition

u. Copy of Shipping Document

9 DELIVERY

Upon successful completion of acceptance testing, the Subcontractor shall assure that the deliverable equipment has been cleaned to a visibly clean condition for use in a clean work area. Each unit of the refrigeration system shall be secured to a transport pallet or integrated forklift design that will allow the assembly to be relocated via forklift. The units are to be packaged to provide protection during shipment to assure safe arrival at KSC in the stated clean condition.

All items shall be accompanied with Form DD250, "Material Inspection Receiving Report." Final acceptance shall be at the NASA destination. Unless otherwise directed, the contractor shall ship all equipment to:

Transportation Officer
NASA Kennedy Space Center
ISC Warehouse, Building M6-744
Kennedy Space Center, FL 32899

Marked for:

Consignee: William Notardonato
Contract Number: TBD
Organization/Office Code: NE-F6
Building No.: O&C, Room 2154F

An Advanced Shipping Notice shall be provided by the contractor prior to shipment. An Advanced Shipping Notice is a courtesy letter or fax which provides advance shipping information to the NASA Contract Administrator to coordinate the receipt of the shipped items with the NASA receiving, transportation, and management personnel. Complete shipping plan due 10 days prior to each shipment. The Contractor shall furnish the following written information to the NASA Contract Administrator or his authorized designated representative five (5) days prior to each shipment:

- a. Date of Shipment
- b. Method of Shipment
- c. Complete or Partial Shipment
- d. Number of Cartons
- e. Total Weight
- f. Dimensions